# NASA Educational Briefs

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## Orbits of Bodies in Space

A knowledge about the science and mechanics of orbits is essential for launching, controlling, and tracking spacecraft. An orbit is the path in space along which an object moves around a primary body. Examples are the Earth's path around its primary, the Sun, and the Moon's path around its primary body, which is Earth.

A single orbit is a complete path around a primary as seen from space. It differs from revolution. A single revolution is accomplished whenever an orbiting object passes over the primary's longitude or latitude from which it started. For example, the Space Shuttle orbiter *Columbia* completed a revolution whenever it passed over approximately 80 degrees west longitude on Earth. However, while *Columbia* was orbiting from west to east around the globe, the Earth was also rotating from west to east. As a result, Columbia's period of (time for) revolution was longer than its orbital period.

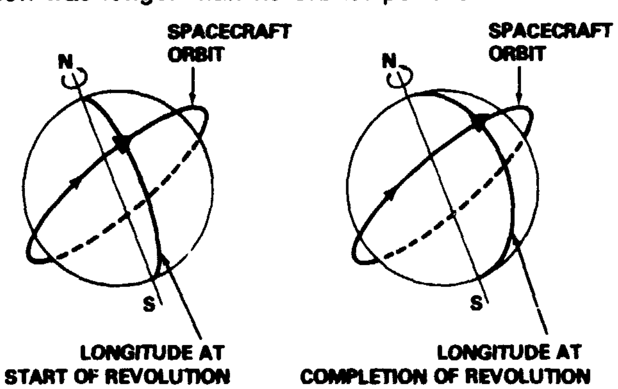
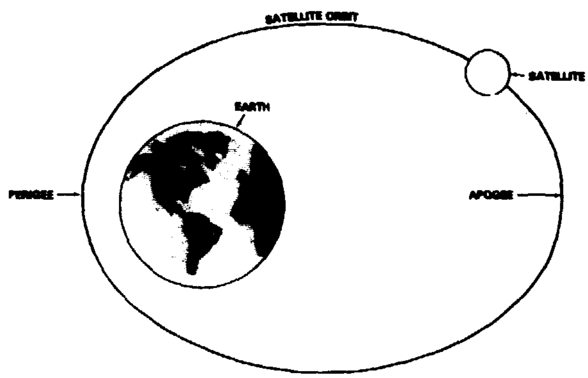



Diagram showing satellite's west-to-east orbit around Earth and how Earth's west-to-east rotation moves longitude ahead. This diagram shows how the revolution period can be longer than the orbital period.

If *Columbia* were orbiting from east to west, its period of revolution, because of Earth's west-to-east spin, would be shorter than its orbital period. An east-to-west orbit is called retrograde as opposed to a posigrade (west-to-east) orbit. If *Columbia* were traveling in a polar (north-south) orbit, it would complete a period of revolution whenever it passed over the latitude from which it started. Its orbital period would be about the same as the revolution period, but not identical because the Earth wobbles slightly north and south.

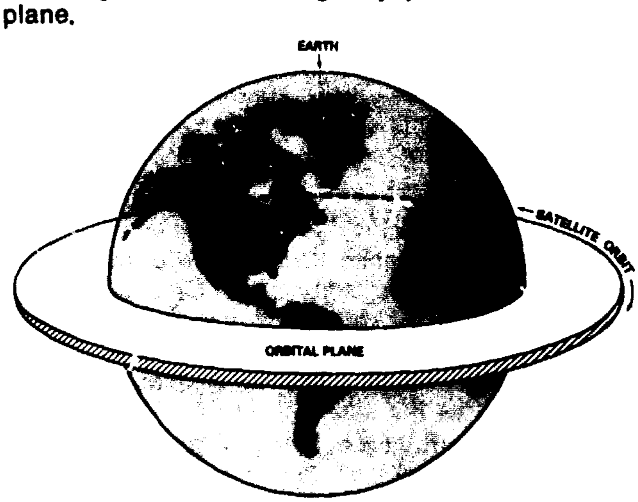
There are certain terms unique to orbits. In orbits, apoapsis is the farthest distance from the primary; periapsis, the shortest. For Earth orbits, the comparable terms are apogee and perigee.




Satellite orbit showing apogee and perigee.

In the case of solar orbits, aphelion describes the farthest point from the Sun; perihelion, the nearest point of an orbit to the Sun.

Another term is the orbital plane. An Earth satellite's orbital plane may be visualized by considering its orbit as the outer edge of a gigantic flat plate bisecting Earth. The imaginary plate is the orbital plane.




An orbital plane may be visualized as a flat plate bisecting Earth.

## Inclination of Orbits

Another orbital parameter is inclination. This refers to the number of degrees the orbit is inclined away from the equator. The inclination also indicates how far north and south the spacecraft will travel in its orbit around Earth.

For example, in STS-2, the second mission of the Space Shuttle, the Shuttle orbiter *Columbia* had an inclination of about 38 degrees. This meant it swept around Earth as far north as 38 degrees north latitude and as far south as 38 degrees south latitude. Because of Earth's rotation, *Columbia* did not pass over the same areas of Earth on each orbit. However, for purposes of description, it may be said that *Columbia* passed over areas as far north as San Francisco and as far south as Melbourne, Australia.

A satellite in a polar orbit has an inclination of about 90 degrees. As such a satellite orbits Earth, it travels alternately in north and south directions. A polar-orbiting satellite eventually passes over the whole Earth because the Earth is rotating from west to east beneath it. An example of a satellite in a nearly polar orbit is NASA's Landsat whose cameras and sensors observe and provide data about Earth and its resources.

A satellite in an equatorial orbit has zero inclination. Examples of satellites in equatorial orbits are commercial communications satellites such as INTELSAT. Later, this brief will describe how by launching satellites into near circular equatorial orbits at the right altitude, the satellites can be made more or less to stand still over a point on the Earth's equator. Such satellites are called geostationary. They are in synchronous orbits, meaning they take as long to complete an orbit as for the Earth to complete a rotation. A satellite at the same altitude in an inclined orbit may also be called synchronous. While the satellite would not move much east or west, it would move north and south over Earth to the latitudes indicated by its inclination. The ground track of such a satellite resembles an elongated figure 8, with the crossover point on the equator.

All orbits are elliptical in accordance with Kepler's first law of planetary motion which is described later in this brief. However, a satellite may be popularly considered in a circular orbit if it is in a nearly circular orbit. A satellite may be popularly considered in an elliptical orbit when its apogee and perigee differ substantially.

## Natural Laws Govern Orbits

Two sets of scientific laws govern orbits whether of natural bodies or spacecraft. One is Sir Isaac Newton's Law of Gravity. Simplified, it is as follows:

1. All bodies attract each other with what is called gravitational attraction. This applies to the largest stars as well as the smallest particles of matter.

2. The strength of a body's gravitational pull upon another is dependent upon its mass which is determined by the amount of matter present. For example, if two bodies are the same size, a body made up mostly of water ice will not have as much gravitational pull as a body made up of iron. This is because water has less mass than iron. You can verify this by weighing comparably sized chunks of ice and iron. (Weight is a product of mass times gravity. Iron has more mass so it weighs more.)

3. The closer two bodies are to each other, the greater their mutual attraction. As a result, to stay in orbit, a satellite needs more speed in a low than a high orbit. For example, *Columbia's* orbital altitude was about 250 kilometers (150 miles). Its orbital speed was about 28,000 kilometers (17,500 miles) per hour. Our Moon, however, which is about 442,171 kilometers (238,857 miles) from Earth, has an orbital velocity of about 3660 kilometers (2287 miles) per hour.

Specifically, Newton's Law states that two bodies attract each other in proportion to the product of their masses and inversely as the square of the distance between them. This calculation is important in launching and guiding spacecraft and is used by astronomers to calculate masses of planets and their satellites.

Any spacecraft launched into orbit moves in accordance with the same laws of motion that govern the motions of the planets around our Sun and the Moon around Earth. Johannes Kepler formulated three laws that describe these motions. They may be presented as follows:

1. Each planet revolves around the Sun in an orbit that is an ellipse with the Sun as its focus or primary body.

2. The radius vector—such as the line from the center of the Sun to the center of a planet, from the center of Earth to the center of the Moon, or from the center of Earth to the center of gravity of *Columbia*—sweeps out equal areas in equal periods of time. (See illustration.)

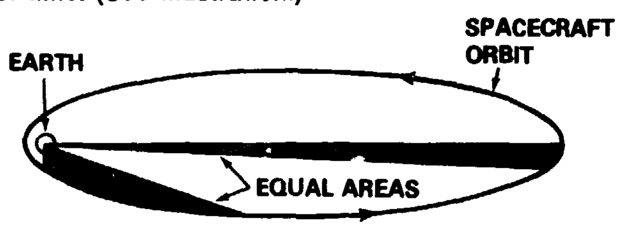



Illustration of Kepler's second law. See text.

3. The square of a planet's orbital period is equal to the cube of its mean distance from the Sun. As extended and generalized, this means that a satellite's orbital period increases with its mean distance from the planet.

In formulating his first law, Kepler recognized no circular orbits—only elliptical ones—determined by gravitational perturbations and other factors. Gravitational pulls, according to Newton, extend to infinity, although their forces weaken with distance and eventually become impossible to detect. However, spacecraft orbiting Earth, while primarily influenced by Earth's gravity and anomalies in its composition, are also influenced by the Moon and Sun and possibly other planets.

## Orbit Durations and Velocities

Kepler's third law says generally that the greater a body's mean orbital altitude, the longer it will take for it to go around Earth. This means that in a rendezvous maneuver where, for example, *Columbia* is trying to catch up with and retrieve an unmanned satellite in the same orbit, *Columbia* must be decelerated. Deceleration would cause *Columbia* to descend to a lower orbit. In the lower orbit, *Columbia's* speed would increase. When properly positioned in the vicinity of the target satellite, *Columbia* would be accelerated to raise its orbit and rendezvous with its target. All of these maneuvers would be precisely controlled by *Columbia's* on-board computer system which is programmed with equations derived from Newton's, Kepler's, and other physical laws.

An interesting and particularly useful phenomenon is the Earth satellite that seems to stand still in space. Examples are our many communications satellites.

Actually, these satellites are not stationary but have an orbital velocity of some 11,000 kilometers (6875 miles) per hour.

Such satellites are in an equatorial orbital plane with an orbital altitude of about 35,580 kilometers (22,240 miles). In this orbital plane and with this altitude, they tend to keep pace with points on the rotating Earth. At the equator, the Earth rotates at about 1600 kilometers (1000 miles) per hour.

These satellites are called geostationary, because they are stationary relative to a geographic point on Earth. This phenomenon can be explained by considering runners on a circular track. The runner in the outside lane needs to run faster than the runner on the inside lane just to keep up with him or her.

A satellite farther out from Earth would appear to someone on the ground to move from east to west although it is also orbiting from west to east. An example that immediately comes to mind is our Moon which, as noted earlier, is about 442,171 kilometers from Earth and has a mean orbital speed of 3660 kilometers per hour. Although this is more than twice the speed of Earth's rotation, the Moon falls back relative to Earth's surface and appears to all of us on the ground to move from east to west despite the fact that it is orbiting from west to east.

## Questions and Activities

1. What is the difference between an orbit and a revolution?
2. In what kind of orbit does a satellite never have a revolution around Earth?
3. Describe Kepler's three laws that govern the motions of planets around the Sun.
4. What do the following terms relating to orbits mean: apoapsis, periapsis, apogee, perigee, aphelion, perihelion, and orbital plane?
5. Read about Isaac Newton in your Encyclopedia. What other physical laws did Newton develop in addition to his Law of Gravity?
6. Give examples of how Johannes Kepler's three laws are used to launch satellites and to send spacecraft to other planets.
7. Demonstrate the principles involved in geostationary satellites.
8. What other satellites besides communications satellites are in geostationary orbits? What are advantages of geostationary orbits?



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